STUDY ON FLOW CHARACTERISTICS OF PRIMARY BLAST FURNACE SLAG

THIS THESIS IS SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF TECHNOLOGY

IN

METALLURGICAL AND MATERIALS ENGINEERING

BY

SANJIB PANIGRAHI

(Roll No. 110MM0370)

&

BIKASH KUMAR SAHOO

(Roll No. 110MM0376)

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
2013-14

STUDY ON FLOW CHARECTERISTICS OF PRIMARY BLAST FURNACE SLAG

THIS THESIS IS SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR

OF TECHNOLOGY

IN

METALLURGICAL AND MATERIALS ENGINEERING

BY

SANJIB PANIGRAHI

(Roll No. 110MM0370)

&

BIKASH KUMAR SAHOO

(Roll No. 110MM0376)

Under the guidance of

Prof. S.Sarkar & Prof. U.K.Mohanty

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

2013-14

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that the thesis entitled **"STUDY ON FLOW CHARECTERISTICS OF PRIMARY BLAST FURNACE SLAG"** submitted by **SANJIB PANIGRAHI** (110MM0370) and **BIKASH KUMAR SAHOO** (110MM0376) in partial fulfillment of the requirements for the award of **BACHELOR OF TECHNOLOGY** Degree in **Metallurgical and Materials Engineering** at the **National Institute of Technology, Rourkela** (Deemed University) is an original work carried out by them under my supervision and guidance.

The matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date: 9th May, 2014

Prof. S. SARKAR & Prof. U.K. Mohanty
Department of Metallurgical and
Materials Engineering,
National Institute of Technology
Rourkela - 769008

ACKNOWLEDGEMENT

We express our sincere gratitude to Prof. B. C. Ray, Head of the Department, Metallurgical and Materials Engineering, NIT Rourkela for giving us an opportunity to work on this project and allowing us access to valuable facilities in the department.

We avail this opportunity to express our indebtedness to our guide Prof. U. K. Mohanty & Prof. S. Sarkar Department of Metallurgical and Materials Engineering, NIT Rourkela, for his valuable guidance, constant encouragement and kind help at various stages for the execution of this dissertation work.

We are also grateful to Mr. Uday Kumar Sahu, Department of Metallurgical and Materials Engineering, NIT Rourkela for providing valuable assistance and insight during the experimental process.

Date: 9th May, 2014

BIKASH KUMAR SAHOO (110MM0376)
SANJIB PANIGRAHI (110MM0370)
Department of Metallurgical and
Materials Engineering,
National Institute of Technology, Rourkela
Rourkela-769008

Contents

ABSTRACT

The primary slag generated in the cohesive zone of the blast furnace determines the fuel rate as well as the quality of the hot metal in terms of its silicon content. This is because in the cohesive zone the softened slag chokes the path of gas flow, interfering with the permeability of the bed. Therefore, the cohesive zone which starts with the softening of the primary slag and ends with its flow should be formed lower down the furnace and should be a narrow one with a minimum difference between the flow temperature and the softening temperature. In the present work pellets with C/S ratio ranging from 1.8 to 2.4 with a fixed MgO content of 10% are reduced in the laboratory at different temperature ranging from 1200 C – 1400 C. Synthetic slags prepared in the laboratory in line with the comparison of reduced pellets are analyzed for its flow characteristics using the heating microscope (German Standard 51730). It is observed that under the composition examined, the pellet with C/S ratio 2.0 rendered the best result with the highest softening temperature and lowest flow temperature.

Keywords: Cohesive zone, primary slag, C/S ratio, Flow characteristics.

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1. INTRODUCTION

Instead of the diminishing coal reserves, and the coke quality issues blast furnace mode of iron making still remains the major route of iron making processes in India and world due to the unavailability of equally feasible and effective method of iron making. The Iron making process is carried out in blast furnaces, approx. 30mtrs in height, with an input of 1.7 ton to give 1 ton of hot metal and slag which mainly consists of oxides of Al, Si, Ca, Mg, Mn, Ti, Fe,Na,K.

A blast furnace uses high temperature counter current to reduce iron ore where in the iron bearing materials and coke are alternately charged along with a suitable flux to create a layered burden in the furnace. Thus permeability of the burden is a chief concern since the process is chiefly dependent on the ascent of gases from the tuyere level to the top of the furnace. The location and extent of cohesive zone plays an important role in this as the iron bearing material layers start softening and melting in the cohesive zone under the influence of the fluxing agents at the prevailing temperature which reduces the layer permeability and thus hamper the regulated flow of materials (gas/solid) in the furnace. The zone is bound by softened iron bearing materials at the top and melting and flowing of the same at the bottom [1]. Thus a narrow cohesive zone, which can be achieved by a high softening temperature coupled with a relatively low flow temperature is desired [2]. Thus, the distance travelled by the liquid decreases, decreasing the en-route Silicon pickup [3, 4]. Moreover, the final slag that trickles down the Bosh region to the Hearth, should be a short slag that starts flowing as soon as it softens. The study of flow characteristics with the help of the characteristics fusion temperature study of the slag is important to evaluate the effectiveness of BF slag [5].

The four characteristics temperatures are known to be; IDT, the initial deformation temperature symbolizing the surface stickiness, important for

movement of the material in the solid state; ST, it indicates the start of plastic distortion; HT, the liquidus temperature, it symbolizes the sluggish flow of the melt which plays a significant role in the aerodynamics of the furnace and FT, the flow temperature, symbolizing liquid mobility.

In the cohesive zone, primary slag is formed with FeO as the primary fluxing constituent. This FeO affects the solidus temperatures, fusion temperature and solidus-fusion interval significantly [6]. However, the primary slag is completely different from the final slag where the basic constituents of fluxing are CaO or MgO. Primary slag cannot be collected from industrial blast furnace, thus a synthetic slag is required to study its flow characteristics and effectively optimize the location and extent of the cohesive zone.

Considering the facts and complexity, preparation of synthetic slag and the study of its flow characteristics so obtained the present work which involves itself with analysis on the basis of the chemical composition of the slag.

LITERATURE SURVEY

2. LITERATURE SURVEY

2.1. BLAST FURNACE IRON MAKING

The blast furnace process is the most dominating iron making process due to its high production rate and very high degree of heat utilization (85-90%). The high degree of heat utilization is credited to the extremely efficient counter current heat exchange setup within the blast furnace. A properly working blast furnaces with the help of the modern techniques today can produce of around 12000 tons of hot metal per day [7].

The oxides of iron occurring in natural form as Haematite (Fe2O3) and magnetite (Fe304) is used as the source of iron in the blast furnace, however sometimes small proportions of hydroxides and carbonates are also used. Heamatite is mainly used for economic production of iron through blast furnace method. Theoretically, heamatite should contain about 70 % of iron and magnetite around 72.4%, however, the iron content of ores ranges from 50-65% for rich ores and 30-50% for lean ores, the rest consists mostly of silica and alumina as well as minor amounts of moisture and chemically combined water and is called the gangue component in the ore. To maintain proper bed permeability, the size distribution of the charge is the chief concern, but the naturally occurring ore has random shapes and size, thus they are processed by means of sintering and pelletizing before charging into the blast furnace. Sintering and pelletizing are processes by which the iron ore fines are agglomerated into larger pieces with or without incorporation of lime and magnesia as fluxes. The insoluble gangue materials in liquid iron possess very high melting points, but they can fuse at lower temperatures in the presence of fluxes to form slag. Magnesia helps to lower the fusion temperature and increase the fluidity of the slag. Lime and magnesia are

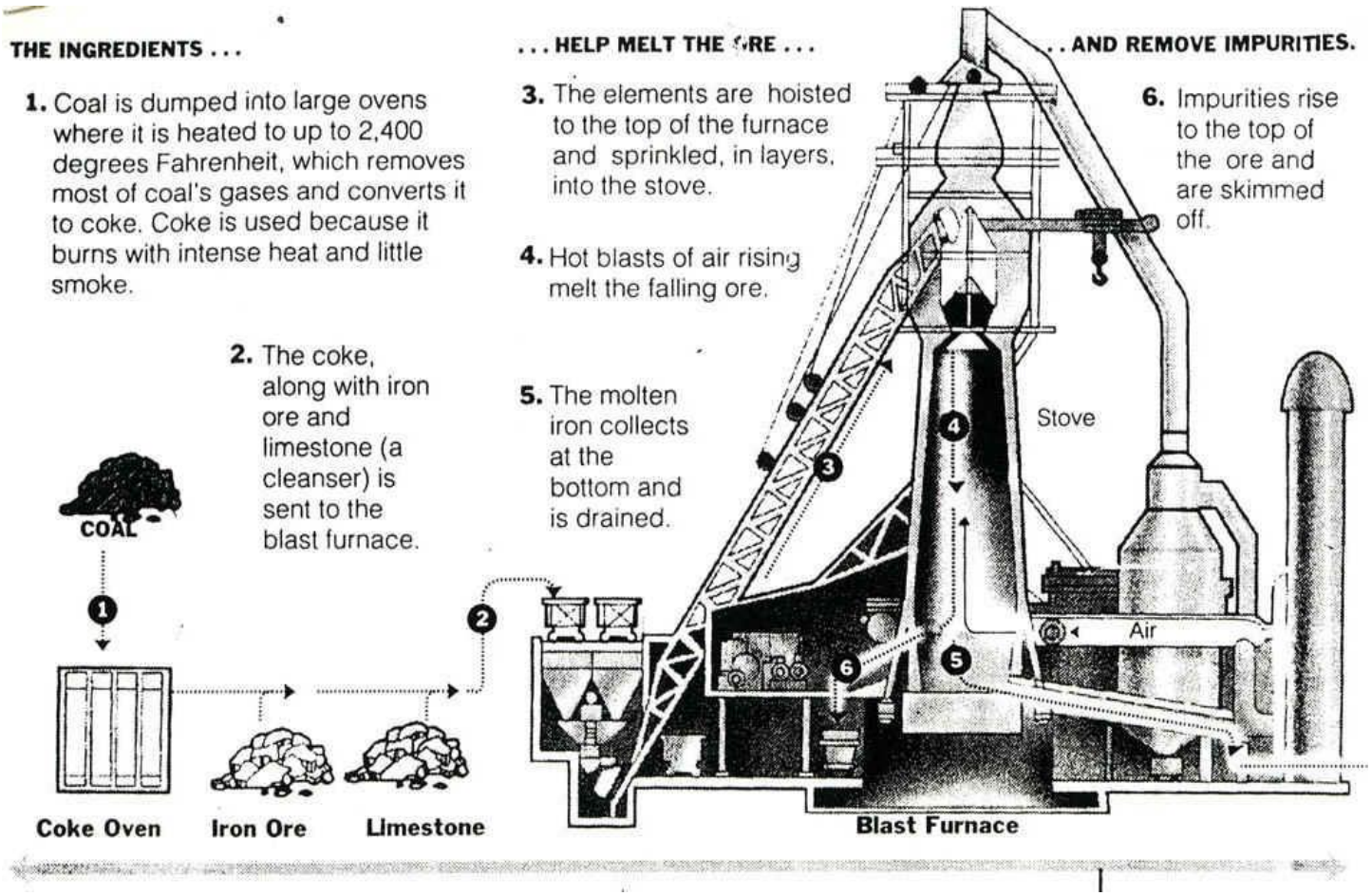
basic in nature and silica and alumina are acidic in nature and their ratio is known as basicity [7, 8].

The slag and iron can only be separated completely from each other on in their liquid state and this requires them to be heated above their fusion temperatures. Moreover, the reduction of iron oxides also needs sufficiently high temperatures as well as adequate amounts of reducing agents (coke carbon). This heat is usually supplied by burning of coke. The iron also picks up 2-4.5% carbon from the coke which lowers its melting temperature from 1534 C by 200-300 C depending upon the carbon content. The coke contains ash which is mainly constituted of silica and alumina which require a further amount of lime and magnesia for fluxing. The ore, coke and flux contain compounds of Si, Mn, P, S and small amounts of other impurities like Pb, Sn, Cu, Ni, Cr, Ti, alkali metals, etc., which get partly or wholly reduced and get taken up by iron. Manganese ores are usually deliberately added for manganese's beneficial effect on iron making.

The burning of coke requires oxygen. This required oxygen is supplied to the furnace in the form of mixture of oxygen and gas, known as blast. The blast is preheated in order to supply sensible heat from outside, hereby reducing coke expenditure. In modern Iron making process, the blast is preheated by burning the blast furnace gas which comes out of the blast furnace top usually containing 20-30% CO and 10-20% CO2 and thus a part of the used chemical heat in the form of CO is utilized indirectly. The blast is introduced above the bottom of the furnace through water –cooled tuyeres whereas the burden material are charged from the top.

Coke is the only component among the charge materials that descends as solid to the tuyere level. Being the only solid in the tuyere region, apart from supplying the reducing agent and heat for processing the burden into finished products, the coke also provides mechanical support to the burden especially in the bosh region where the metal and slag are liquid. The

interstices of the coke grid allow the liquid to flow down to the hearth. The coke rate in the blast furnace per ton of pig iron varies from 1000kg to as low as 45-500 kg. Low coke rates are obtained with pre-fluxed sinters and pellets, high blast temperatures and uniform gas distribution. The hot blast of air entering the furnace through the tuyeres burns the coke carbon to CO2 immediately in front of them. The intense heat produced gives a flame temperature as high as 1800-2000 C, depending upon the blast temperature. Since CO2 is unstable in the presence of carbon above 1000 C, CO is produced. The tuyere gas, therefore consists only of CO and nitrogen, when dry blast is used. The coke doesn't fall continuously but only periodically in to the tuyere zone from above. The hot reducing gas rises through the active



coke bed to the bosh, belly and the shaft and reduces the iron oxides [8, 7].

Figure 1. An overview of blast furnace operations.

2.1.1. REDUCTION OF IRON OXIDES

There are three forms of iron oxide: hematite (Fe2O3), magnetite (Fe304) and Wustite (FeO). These oxides are reduced in stages. Their reactions with CO, the equilibrium CO/CO2 ratios and CO-utilization factors at 900 C are given below. The extent of CO utilization, i.e., the fraction or percentage of CO converted to CO2 is recorded in terms of a fraction percentage as shown below, [7]

$$\%CO\text{-utilization} = 100 \times \%CO_2 / (\%CO_2 + \%CO) \qquad \text{Eq. 1}$$

Reactions	*Equilibrium at 900oC*		
	CO/CO2	*%CO-utilization*	
$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$	0	100	Eq.2
$Fe_3O_4 + CO = 3FeO + CO_2$	0.25	80	Eq.3
$FeO + CO = Fe + CO_2$	2.3	30	Eq.4

The blast furnace is a counter current process. Thus, the tuyere gas with high CO-content comes into contact with the Wustite which needs a very high reduction potential for conversion to Fe (Eq. 4). The resulting lower potential gas, as it ascends, encounters magnetite and hematite which require much smaller equilibrium CO/CO2 ratios for reduction to lower oxides. Hence, the reduction of Wustite is of prime importance in iron oxide reduction, especially because about 70% of hematite oxygen is present as Wustite.

Since CO2 represents the end combustion product of carbon, the utilization of the chemical and thermal energies of carbon will be more complete if higher amount of oxygen is removed by reactions Eq.2 to Eq.4. These reactions are called indirect or gaseous reduction and the reaction product is CO2. The overall reaction from Eq.2 to Eq.4 is mildly exothermic [8].

If any Wustite remains unreduced in a zone where temperatures are higher than 1000oC, the CO2 produced by reaction 4 is rapidly reduced by carbon according to:

$$CO2 + C = 2CO - 41210 \text{ cal} \qquad \text{Eq.5}$$

Combining equations 4 and 5,

$$FeO + C = Fe + CO - 37220 \text{ cal} \qquad \text{Eq.6}$$

Reaction 5, known as Boudouard or solution loss or carbon gasification reaction is highly endothermic and also deteriorates CO-utilization. Reaction 6 is called direct reduction and is endothermic in contrast to indirect reduction but consumes less carbon for every mole of oxygen removed because the product, CO, can take part in further (gaseous) reduction [7].

2.1.2. REACTIONS IN THE LOWER ZONE :

The lower or melting zone extends from the tuyere level to 3-5m above. The temperature of the molten materials reaches 1400-1450oC in this zone and the gas cools down to 800-1000oC. The burning of coke in front of the tuyeres result in a continuous creation of an empty space around the hearth periphery which permits the flow of the charge materials downwards. This combustion zone constitutes an active area as a ring of 1-2m depth and is called the raceway. Beyond the raceway, there is a closely-packed central column of coke called dead man's zone. The coke column either floats on

the liquid iron in the hearth or reaches as far as the hearth floor. Some slag and iron remain entrapped in the interstices of the coke pieces and are drained out during tapping [7].

The gangue in association with the flux starts to fuse in the belly region where two immiscible phases (partly carburized primary iron and FeO-SiO2-Al2O3-MnO primary slag containing some CaO) begin to form at temperatures above 1200oC. Further down, these liquid phases separate from each other, infiltrate through the coke grid above the raceway and collect in the hearth well from where they are tapped periodically. Since the tuyere gas also rises through the voids of the coke bed, the raceway resembles a counter-current liquid-gas exchanger, the coke providing the mechanical support [8].

The minimum hearth temperature necessary for free running of the slag is termed as critical hearth temperature which is about 1500-1550oC in order to provide some superheat in the hearth and ensure that both slag and iron are in the liquid state under all operating conditions. The more important chemical reactions occurring in this zone are [7]:

1. Endothermic calcinations of limestone; $CaCO3 = CaO + CO$

2. Endothermic direct reduction of FeO; $FeO + C = Fe + CO$

3. Endothermic direct reduction of SiO2; $SiO2 + 2C = Si + 2CO$

4. Endothermic direct reduction of MnO; $MnO + C = Mn + CO$

5. Endothermic direct reduction of P2O5; $P2O5 + 5C = 2P + 5CO$

6. Endothermic sulphur removal; $FeS + CaO + C = CaS + Fe + CO$

7. Exothermic combustion of carbon; $C + O2$ (air) $= CO2 + N2$

8. Endothermic reduction of CO2; $CO2 + C = 2CO$ (>1000oC)

9. Endothermic reduction of moisture in blast; $C + H2O = CO + H2$ (>1000oC)

The final temperature of iron is about 1350-1450oC and that of slag about 50-100oC higher. Depending upon the raw materials and finished products, the

heat requirement in the lower furnace including radiation and cooling losses may range from 0.7 to 1.0 million kcal per THM. This results in rapid cooling of the tuyere gas from about 2000oC to 800-1000oC since all the above heat devouring reactions occur above 900ºC [7].

2.1.3. REACTIONS IN THE MIDDLE ZONE

This zone, where the temperatures of the solids and the gas are near identical (800-1000oC), is called isothermal or reserve zone. Most of the Feo reduction takes place in this zone, so it is also called as indirect reduction zone. It occupies 50-60% of the volume of the furnace. In this zone majority of the indirect reduction of oxides of iron according to Eq.2-4 occurs. The length of this zone is important because FeO should be given ample opportunity for getting reduced indirectly.

Insertion probes to modern furnace shows the presence of chemically inactive zone inside this zone where little exchange of oxygen between the ore and the gas takes place and the gas composition suffers very little change. In inactive zones the CO/CO2 ratios of the gas is about 2.3. This zone becomes pronounced in cases where the coke consumption per THM is very low. Water gas shift reaction also an important reaction which takes place in the middle zone:

$$CO + H2O = CO2 + H2 \qquad \text{Eq.7}$$

This reaction generates hydrogen which is more active reductant than CO. The moisture is originated from the reduction of iron oxides along with hydrogen which itself sourced from humid air or when hydrocarbons and steam are used as blast additives [8].

2.1.4. REACTIONS IN THE UPPER ZONE

In the upper zone, the ascending gas temperature from the middle zone falls rapidly from 800-1000°C to 100-250°C and that of solids rises from ambient to 800oC. The main reactions that occur in this zone are:

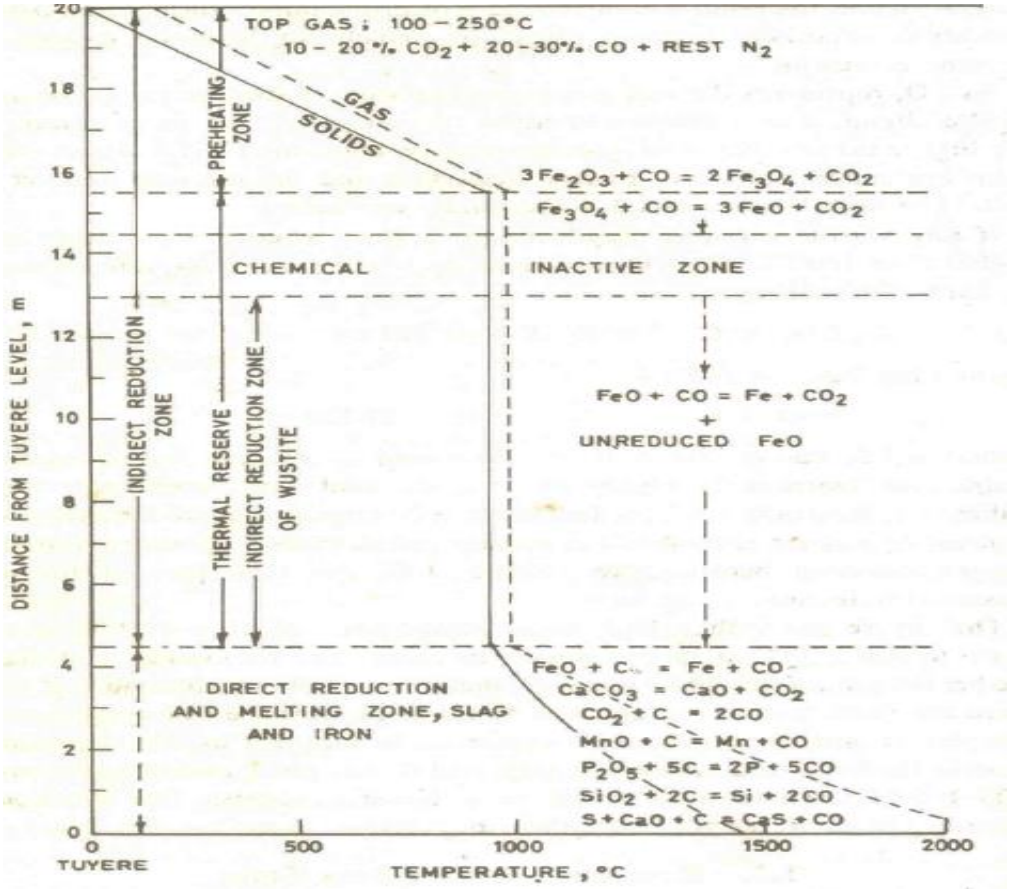
1. Carbonate decomposition other than calcium carbonates

2. Moisture vaporization and water hydration of the burden

3. Carbon deposition, $2CO = CO_2 + C$

4. Reduction of magnetite and hematite to their lower oxides, partially or completely

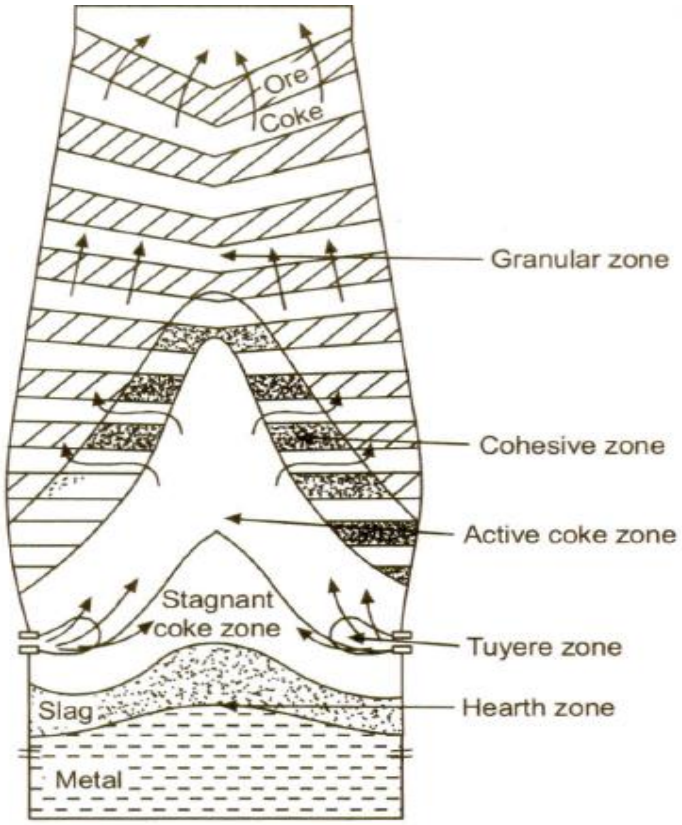
Depending on the rate of production it takes around 6-7 hours for any burden to descend from the top to the tuyere level depending upon the rate of production [8].



Ce

Figure 2. Different chemical reaction taking place inside blast furnace

2.2. DIFFERENT INTERNAL ZONES IN BLAST FURNACE



Schematic sectional diagram of the internal zones in a blast furnace.

at the top of the furnace is the granular zone that contains the coke and the iron bearing materials charged, sometimes along with small quantities of limestone and other fluxes. The iron-bearing oxides charged get reduced to wustite and metallic iron towards the lower end of the granular zone.

As the burden descends further, and its temperature rises on account of contact with the ascending hot gases, softening and melting of the iron-bearing solids takes place in the so-called cohesive zone (mushy zone)[8].

2.2.1 Cohesive Zone in the B.F.

Out of five zones the cohesive zone plays the most important role in the B.F. operations. This is the zone where the ferrous burden soften and melt. Its shape, position and extent in the B.F. affect the gas flow pattern. The burden loses its permeability. Gas flow occurs only through the coke layers. Loss of permeability is caused by liquid phase in the ferrous burden. The liquid formation causes a pressure drop. Also the solid phase gets deformed due to the weight of the burden. This deformed solid may occupy the gaps between the solid ferrous pieces also causing loss of permeability. The different phenomena simultaneously occurring in the cohesive zone are:

- softening and melting of the oxide phase.
- b. carburization of the metallic phase
- c. softening and melting of the metallic iron phases

Softening and melting of the oxide phase will be affected by:

- the quantity of nonferrous oxide (slag formers) present
- distribution, morphology and chemistry of slag formers
- degree of pre reduction (this will affect the availability of FeO as a slag former).

2.2.2 DESIRED LOCATION OF THE COHESIVE ZONE

Cohesive zone should be formed lower down the bosh (results in increase in the granular zone, increase in the gas utilization, decrease in the volume of the dripping Zone, decrease in the contact time between SiO gas and hence Si pick up by the metal.) Lowering of cohesive zone can be achieved by a high softening temperature of the burden material. The thickness of the cohesive zone should be low (a thinner cohesive zone is expected to allow more air passage for a given pressure deferential), hence FT-ST should be low.

2.3. BLAST FURNACE SLAG

2.3.1. OVERVIEW

Iron blast furnace raw materials consist of gangue minerals and coke ash in combination with fluxes – usually lime and magnesia. The principal oxides of the minerals are alumina and silica and they are removed by the addition of flux, the resulting liquid slag being insoluble in and lighter than the molten iron forms a separate layer. Basic flux is necessary not only to lower the melting points of the acid constituents and thereby obtain a liquid or sufficiently fluid slag but it also takes part in the slag-metal reactions and controls the metal quality, viz., the Mn-, Si- and S-contents [7].

A proper slag should perform a variety of functions for maximum efficiency both in fuel as well as furnace performance; it should determine, control or possess the following:

1. Metal temperature
2. Metal quality, i.e., the C, Si, Mn, S and FeO contents of iron;
3. Homogeneity, absence of crystalline phases, i.e., the melt should not undergo variations in its physical properties;
4. Tolerance of fluctuations in the temperature and physical and chemical properties of the burden which constantly occur even under the best operating conditions; the slag should cushion such shocks without materially affecting its properties and furnace performance;
5. Sulphur retention potentiality, i.e., a high (S)/[S] ratio under the operating conditions;
6. Low viscosity, i.e., the slag should be able to run out of the furnace freely and rapidly at the operating temperatures; as the coke rate is affected by the 'critical temperature' which will enable the slag to flow, the free running characteristic of the slag will affect fuel economy;

7. Free movement of the stock and furnace gases; these are determined by the physical properties and zones of fusion of the primary and bosh slags which greatly affect the productivity of the furnace and the quality of the products;
8. Suitability of the slag for use in cement manufacture, road ballast, etc.

On the other hand, the course of primary and bosh slag formation is itself affected by the operating and other conditions, namely, flames temperature, distribution of materials at the top, ore reducibility, burden yield(i.e., slag bulk), sinters and pellets (acid, fluxed or super-fluxed), softening temperatures of the ferrous charge, coke ash content, furnace lines, etc.

The course of slag formation in the blast furnace can be divided into three zones:

i. Primary slag fusion zone;
ii. Bosh slag fusion zone;
iii. Final slag or hearth slag zone.

2.3.2. FORMATION OF PRIMARY SLAG

Partially reduced iron oxide in combination with the gangue form easily fusible eutectics with alumino-silicates with or without lime, magnesia or MnO. The zone of softening and melting of the initial slag depends upon the temperature distribution in the vertical as well as horizontal cross-sections of the furnace. The location, extent and temperature range of softening and melting are of great importance for gas through flow, productivity and smooth running of the furnace. The properties and behavior of the initial slag

formed depend upon the nature and mineralogy of the burden, i.e., whether the charge consists of raw ore or acidic or basic agglomerates [7].

2.3.2.1. RAW ORE

In raw ore plus limestone burden, the calcination and assimilation of the latter occur slowly and are complete only when very high temperatures are reached, i.e., in the bosh, tuyere and hearth zones. Therefore, the initial slag formed is acidic consisting essentially of unreduced FeO and gangue silica and alumina with some MnO, the fusion temperature depending upon the FEO-content. When the ore is lean and highly reducible, the %FEO-content of the slag is low and its fusion temperature high, 1200-1350 C. On the other hand, in rich ore with low slag bulk the %FeO is comparatively high even if it is highly reducible and its fusion temperature low, about 1200 C. Since direct reduction and the temp of fusion rises, the % FeO decreases as the primary slag goes down. The presence of MnO and absorption of lime and magnesia keep the slag molten during its passage to the hearth. The fluxing action of MnO is similar to that of FeO but the free energy of MnO being much smaller it is reduced at high temperatures in the bosh and the hearth, only partly, never to completion.

Ideally, the primary slag should start to soften, melt and contract in the belly with its wide transverse dimension designed specifically to allow gas flow through the semi-fused viscous party mass. However, as seen above, the melting temperature, melting zone or even the slag composition are not constant in time or place [7].

Softening or melting may start even in the middle of the furnace in the case of a strong peripheral flow, center overloaded with ore, use of fine ores or ores with low softening temperatures around 700-800 C.

2.3.2.2. ACID SINTER

In acid sinter, the primary slag is pre-formed and, therefore, its mineralogical composition, softening-melting temperatures and other physical properties are more or less predetermined. It softens gradually in a much narrower temperature range than in the case of raw ores because of greater homogeneity but otherwise the physical nature of the acid slag is similar. It, being less reducible, carries more FeO which together with MnO gives a low-melting slag. Such a slag is disadvantageous in the blast furnace, especially if it carries a lot of Fe), since it descends inadequately heated and prepared and disturns the thermal state of the hearth. The wide fusion range and high fusion temperatures promote the formation of a party mass at a higher level of the furnace which hinders gas through flow and causes an erratic stock descent. However, acid sinter is a much better feed material than the raw ore [7].

2.3.2.3. BASIC SINTER

Basic sinter softens and melts almost simultaneously in a high and narrow range of temperatures since its FeO content is low, it being very reducible. IT acquires a high fluidity as soon as it melts. Since it does so at a high temperature and in a short zone in the belly or upper bosh it promotes a high production rate and the adequate preheating ensures a stable furnace operation and metal quality. Its drawback lies in the fact that as it melts quickly it can also re solidify as rapidly during variations in the blast humidity and temperature [7].

2.3.2.4. LIQUIDUS TEMPERATURE AND VISCOSITY

The liquidus temperature of the primary slag depends upon the various components present in the main ferrous alumina-silicate system. However, it is

known that small amounts of lime and magnesia decrease the liquidus temperature which increases with their increasing amounts.

The liquidus temperature of the ferrous alumina-silicates depends not only upon the FeO-content but also on the silica-alumina ratio. It is evident that the slag has to pass through high temperature regions near the alumina-silica binary. For any given %FeO in slag, the lowest melting points are obtained for silica/alumina ratios of 2.5:4.0:1. For a final slag silica of 35-40 percent, this corresponds to 10-15% Al_2O_3. In fact, such slags have been found to be most conducive to smooth furnace operation.

The dissolution of lime and therefore the formation of the bosh and subsequently that of the hearth slags will be smooth when the silica/alumina ratio is optimum. If not, a highly refractory slag and irregular furnace operation may result depending upon the %FeO-content, since the fusion temperatures rise with higher or lower ratios. One of the reasons why it is so difficult to work with Indian blast furnaces is the very low ratio, 0.25-0.5:1, in the Indian iron ores. Hay and Schroeder have shown that both high and low alumina slags are more viscous than the medium ones (10-18% Al_2O_3). However, they can be thinned by the use of MgO [7].

The viscosity of the primary slag also plays a role in stock descent, rate of lime dissolution and stickiness in the bosh. Both FeO and MnO markedly thin the slag. The latter must be present in increasing quantities as the basicity increases in order to keep the slag fluid as otherwise the slag may resolidify as the FeO is progressively reduced. Since MnO is difficult to reduce, its presence | (2-10 percent) helps to broaden the range of fluidity and stabilize the viscosity of the primary slag under the operating conditions. For making low-Mn iron, in the absence of sufficient MnO, the slag must be kept fluid additions of MgO. Primary slags from self-fluxing sinters have viscosities of 1-2 P even without FeO or MnO.

MnO is also very helpful in retaining the fluidity of acid slags. It reduces the viscosity of slags of basicity CaO/ SiO2 = 0.6-0.8 by about 2-5 times. This allows working with extremely acid slags of basicity 0.3-0.9.

When the slag is excessively limey, it becomes very refractory as happens with rich Indian ores with high coke rate and high coke ash content. In case of any sudden reduction in temperature such slags are apt to solidify. They can be thinned to a certain extent by MgO or MnO but the latter in excessive amounts increases the cost as well as steelmaking difficulties. Acid slags are more immune in this respect since they retain their fluidity even at considerably lower temperatures. The formation of scabs arising from the walls by suitable charging sequence, e.g., OOLCCC or OOCLCC. The walls can also be washed with occasional use of hard-blunt acid sinter or by charging acid sinter first [7].

Modern furnaces working with low slag volume, pre-fluxed slag containing magnesia and comparatively high FeO seldom show furnace irregularity because of lower, uniform and narrow range of melting temperatures and very favorable fluidity.

2.3.2.5. EFFECT OF BLAST TEMPERATURE

The formation of a molten slag and its subsequent resolidification can adversely affect gas through flow and stock descent. Since high blast temperature lowers the slag fusion zone from the belly to the bosh region, the danger lies more in the case of lean, ores with high reducibility (very low %FeO) because of the formation of a low-FeO highly viscous primary slag in the bosh incline rather than in the belly. This leads to increased viscosity and 'gumminess' of the bosh slag as well as late fusion and consequent late contraction of the material volume in the region. Plant experience shows that it is difficult to use high blast temperatures in the lean ore practice because of the tendency of the furnace to hang. Such bosh hangings are removed by lowering the blast temperature (or by decreasing the flame temperature by any means) which moves the fusion zone to a higher level. Easily reducible

American Mesabi ore is an example where the furnaces could not take blast temperatures higher than about 450-500 C. The remedy for such ores presumably lies in changing the furnace liens and making a shorter bosh so that even with higher blast temperatures the fusion zone will confine to the belly region [7].

2.3.3. FORMATION OF BOSH SLAG

The lime content of the primary slags is usually low and is on the acid side. This is so because of the belated incorporation of lime in the primary slag. The absorption of lime may be slow but it is continuous and is complete only in the hottest parts, i.e., at the tuyere level. The reduction of Fe only in the hottest parts, i.e., at the tuyere level. The reduction of FeO in the lower, hotter zones is very fast and is almost complete above the tuyeres in the axial zone, however, there may be a considerable amount of slag-FeO due to inadequate penetration of the reducing gases. The resulting bosh slag is much more basic than the final slag because the acid constituents of the coke ash are only absorbed when released at the tuyeres. Bosh slag composition may vary widely depending upon the furnace movement as well as on the individual materials charged, namely, iron ore, manganese ores, sinters or fines , or limestone. The bosh slag basicity is higher the richer the ore (i.e., the lower the slag volume), the higher the coke rate, the higher the sulphur load, the higher the metal silicon, and the higher the coke ash content.

The bosh slag basicity is also a function of the final silicon content of iron, since most of the silicon is reduced from silica above the tuyere level. Hence, for a given final slag basicity, the higher the amount of silicon reduced above the tuyeres, the lower will be the amount of silica in the bosh and the higher will be the bosh slag basicity. The bosh slag which has the highest basicity possesses the greatest desulphurising potential. Iron made with such slags should possess the lowest sulphur content. For the same reasons, low-silicon iron can be made with such slags when using very high blast temperatures [7].

2.3.3.1. IMPORTANCE OF BOSH SLAG

The properties of the bosh slag are of utmost importance for the furnace productivity and metal quality. The more important properties are: [7]

i. High fluidity
ii. Narrow fusion range
iii. High fusion temperature
iv. High basicity
v. Items (ii-iv) above permits the use of highest blast temperatures without affecting the metal silicon or smooth furnace operation

2.3.4. FINAL OR HEARTH SLAG

The hearth slag is formed on dissolution of the lime which was not incorporated in the bosh and on absorption of the coke ash released during combustion. The formation is more or less complete in the combustion zone. The slag retains along with the molten iron into the hearth and accumulates there and forms a pool with the molten metal underneath. During the passage of iron droplets through the slag layer, the slag reacts with the metal and a transference of mainly Si, Mn and S occurs form or to the metal, tending to attain equilibrium between themselves as far as possible. The nature, composition and the bulk of the hearth slag ultimately control the composition of the pig iron and the productivity if the blast furnace.

2.3.4.1. LIQUIDOUS TEMPERATURE AND VISCOCITY

In order that a blast furnace slag be practicable and most effective, it must be completely homogeneous liquid at the operating temperatures. It must also have sufficient fluidity so that it can run out of the hearth freely without any loss of production time. As sulphur is the key to iron quality and the basicity of the slag is the key to low sulphur iron, it is important to ascertain the limitation of the basicity on the slag properties. We are aware that, the

viscosity decreases with increasing basicity while, on the other hand, the melting temperature of the slag increases with increasing lime content. The liquidus temperature of the hearth slag should be below the desired minimum slag temperature because the appearance of any crystalline phase may result in a sharp increase in the viscosity if the slag temperature is close to the liquidus temperature [7].

The hearth slag belongs mainly to the $CaO\text{-}SiO_2\text{-}Al_2O_3$ and $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3$ system. The basicity ratio $(CaO+MgO)/(SiO_2+Al_2O_3)$ determines the slag viscosity above the liquidus and it is progressively lower as the basicity increases. The term above the liquidus is to be noted since the melting point of the slag may increase with increasing lime content.

When working with only a fixed C/S ratio, in a decreasing silica of the pre means charging of less CaO but the percentage of alumina in the slag would increase, rendering it necessary to increase the hearth temperature for obtaining a fluid slag- the slag thus becoming less suitable for producing low Si and low S-Irons.

2.4. BLAST FURNACE SLAG STRUCTURE

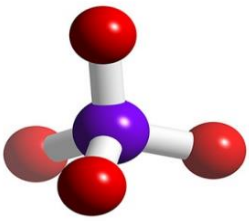
Homogeneous liquid slags consists of silicon oxides and other different elements. They consist of simple and complex ions and possess electrical properties. From crystal analysis it is seen that in silica, silicon is present at the center while 4 oxygen atoms occupy the corner of a tetrahedron. Each oxygen atom is linked to 2 Si atoms & the network is continuous in 3 dimensions. Since these tetrahedral can only share the corners i.e. only oxygen atom is shared, the substance thus formed will have a stoichiometric formula of SiO_2. Si atoms have 4 charges. As every oxygen atom of the tetrahedron has a residual valence, therefore, the SiO_4 group carries 4 negative charges, i.e. $(SiO_4)4-$.

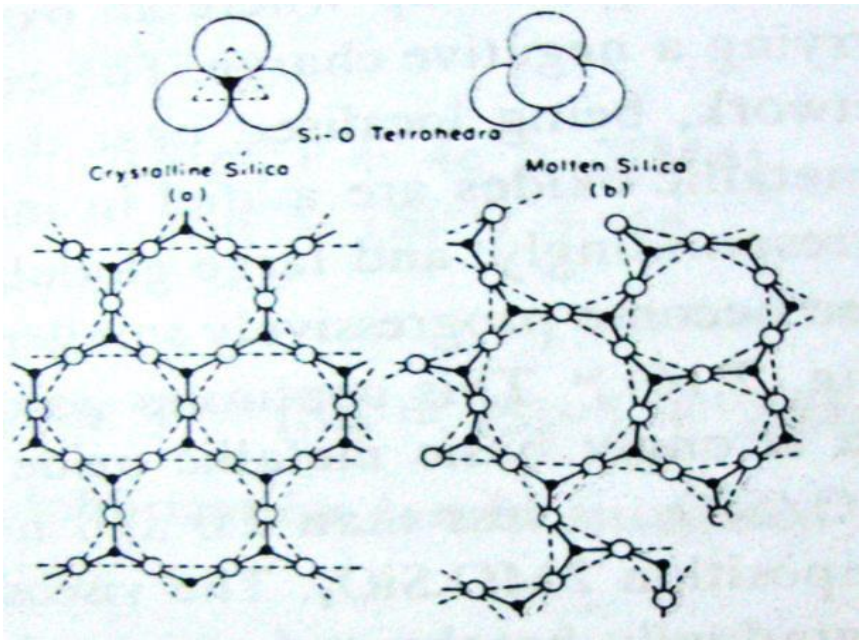
In the crystalline state the tetrahedral arrangement of the silicon and oxygen atoms is symmetrical. The solid structure does not undergo any sudden

change on fusion, as expected. In molten or vitreous silica the structure becomes distorted but most of the corners remain shared. The viscosity of molten silica is very high (≈ 105 P), the corners being linked tightly in all directions in a vast network.

The group, $(SiO_4)4-$ which is regarded as individual tetrahedron with silicon at the centre and oxygen at the four corners, can be assumed to exist as ion in the complex silicates. Measurement of the energy of activation for electrical conductance and other results indicate that the addition of CaO, MgO or other metal oxides to molten silica results in the breakdown of the three dimensional silicon-oxygen network into silicate ions. The driving force for the breakdown process is the attraction between silicon and oxygen. This depends on their relative valances and ionic radii.

When lime or Magnesia is added to molten Silica, two silicon-oxygen bonds are opened up giving rise to an open shared corner where oxygen is added, each oxygen carrying a negative charge. The cations distribute in the interstices of the network, being localized near the charged oxygen. As the metallic oxides





are added in increasing amounts,

Figure 4. SiO_2 Structure

the Si-O bonds break correspondingly, and large globular or ring type silicate ions are formed. These become progressively smaller as the metal oxide

content increases as their no goes on increasing. As the strong silicate networks break, the viscosity of the melt decreases drastically as viscosity of a material depends not only on its composition but also on its structure. The more relaxed the structure is the less is the viscosity [7].

2.5. Softening and Melting Phenomena

The softening of the burden refers to the change in the state of ferrous materials such that it causes an increase in its rate of deformation and decreases the bed permeability. The voids between the materials can be occupied by the exuded liquid and/or fragmented solid pieces. Therefore the deformation of phases and formation of liquid can be the two primary causes which will accelerate the loss of strength of the material under the action of mechanical forces [9].

In cohesive zone or mushy zone, different phenomenon occur at the same time, the softening and melting of the oxide phase and the softening and melting of the metallic iron phase. The strength of the metal phase will depend on the amount of carbon present whereas the strength of the oxide phase depends on the amount of non-ferrous oxides or slag formers present, along with their distribution, morphology and chemistry. It will also depend upon the reduction degree as it affects the availability of iron oxide as a slag former [10].

The softening and melting phenomenon of the ferrous burden is a complex phenomenon and thus can be subdivided into various steps. The first oxide melt is formed at the interface with lowest melting point, usually between and iron oxide particle and another oxide. It thus is heavily dependent on the phases present and their distribution. The first melt formed will subsequently wet the ore particles due to reduction in interfacial energy. This liquid film will slow he reduction kinetics as it inserts another resistance to the reaction, i.e. an additional step of transportation through the liquid slag film. This is

often referred as reduction retardation. It has been observed that in majority of the blast furnaces, the metallic burden reaches its softening temperature with a reduction degree higher than 50 percent. Hence we can assume that there is a porous solid iron shell confining the solid and liquid oxides. As the liquid phase covers the solid oxide particles, it becomes a semi-solid material, where the liquid slag layer acts as a lubricant for the remaining particles. As a result of the wetting of the ore particles by the liquid slag, the core has a much reduced mechanical strength and the resistance to deformation will be determined by iron shell. The ability of the metallic shell to hold the molten oxides together will depend on its strength and reduction degree. With increase in liquid volume fraction with increase in temperature, subsequently a point will be reached when the iron oxide will not be able to hold the liquid. This will cause the dripping of the liquid slag from the burden material. In the meanwhile, the reduced iron shell is being carburized, and the temperature is continuously rising. As the liquid oxide fraction increases, it will also tend to transferred from the core to metallic shell. This is due to reduction of overall free energy as the interfacial energy between liquid and Wustite is larger than that between liquid and metallic iron. This however does not cause exudation of the burden [10].

Softening is defined as the moment when the metallic burden can no longer withstand the action of mechanical forces. This generally coincides with the dripping of material from the burden component. The dripping will be a competition between increase in liquid slag volume which increase the pressure on the shell, and the carbon content of the iron shell, which reduces its strength. Both these parameters tend to increase with temperature. The reduction degree will remain constant during this, because the reduction kinetics is slow after the reduction retardation. Thus, the dripping is triggered by the onset of melting in the oxide region, which in equilibrium occurs at the

solidus temperature. The burden then subsequently melts and moves down to hearth where the hot metal layer and slag layer get separated due to the difference in their density [10].

2.5.1. Shortness of a Slag

The softening and melting phenomena of blast furnace slag is of vital importance in BF operation as it has a direct say over the productivity and efficiency of the process. The characteristic temperatures obtained from the flow characteristics of blast furnace slag includes; Initial Deformation Temperature (IDT), Softening Temperature (ST), Hemispherical Temperature (HT) and Flow Temperature (FT). The ST and FT rheologically signify the plastic distortion and liquid mobility of the blast furnace slag respectively. The difference between the flow temperature and softening temperature is termed as the 'shortness' of the slag. In a blast furnace operation, a short-slag is desirable as it trickles down the furnace as soon as it is formed thus exposing further reaction sites for better slag-metal reaction rates. Shortness of the slag has a direct impact over the furnace productivity as it controls he slag-metal reaction rates.

2.5.2. Flow Characteristics of Blast Furnace Slag

To determine flow characteristics high temperature microscope is used for slag sample. It has got four characteristics temperatures to be studied:

- Initial deformation temperature (IDT)
- Softening temperature (ST)
- Hemispherical temperature (HT)
- Flow temperature (FT)

The followings are defined as per German Industrial Standards 51730. [5]

- **Initial Deformation Temperature (IDT)**

It is the temperature at which the first rounding up of the edges of the cube-shaped sample specimen takes place. In fact this is the temperature at which the first sign of the change in shape appears.

- **Softening Temperature (ST)**

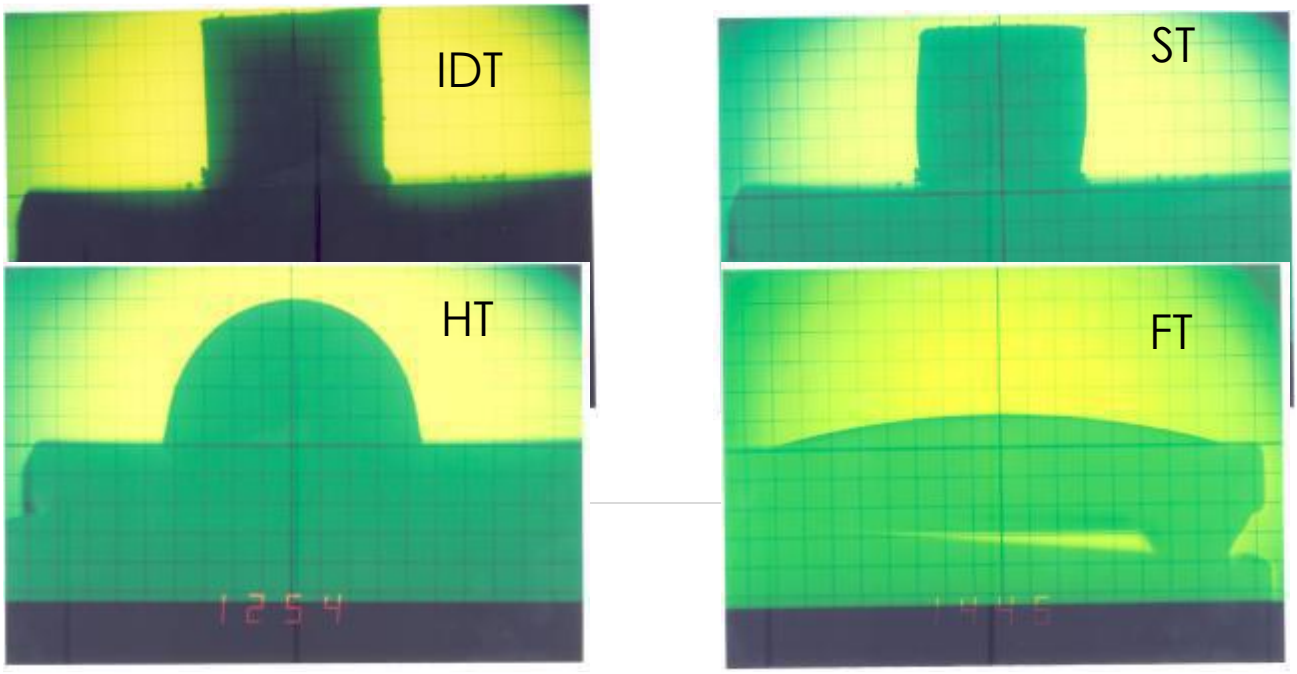
It is the temperature at which the outline of the shape of the sample starts changing and is reported as the temperature at which the sample shrinks by one division or the temperature at which the distortion of the sample starts.

- **Hemispherical Temperature (HT)**

It is the temperature at which the sample has fused down to hemispherical shape and is measured as the temp at which the height of the sample is equal to the half of its base length. This is defined as the fusion point or the melting point.

- **Flow Temperature (FT)**

It is the temperature at which the sample liquidities and is reported as the temperature at which the height of the sample is e (hemispherical temperature). Though some books reported as the temperature at which the height becomes one third of the initial height. The former is more accurate and is universally accepted.



2.6. Effect of Slag Constituents on Liquidus Temperature

The liquidus temperature influences the position and width of the cohesive zone which directly controls the productivity of the blast furnace operation. The positioning and width of the cohesive zone controls the gas permeability, Si content in the hot metal and the extent of indirect reduction inside the furnace. Thus the determination of liquidus temperature of the slag is of vital importance.

The liquidus temperature has been mentioned by different terms by different scientists. Osborn [11] and Snow [12] reported liquidus temperature as the temperature at which the first crystal forms during cooling down the melt. Ohno et al [13] reported it as the temperature at which the last crystal disappears during heating. German Industrial Standards 51730 defines it as the hemispherical temperature, i.e., the temperature at which a small mass of the slag assumes the shape of a hemisphere on heating. The heating microscope method is adopted to measure this hemispherical temperature.

When a pyro metallurgical process is carried out in a furnace, it is the flow characteristics of the non-metallic melts (i.e., the mixture of oxides which would combine to make the slag) which is more important than the exact fusion temperature. The flow characteristics are defined in terms of four characteristic temperatures. These are; the initial deformation temperature (IDT), symbolizing the surface stickiness; the softening temperature (ST), symbolizing the plastic distortion; the hemispherical temperature (HT), which is also the liquidus temperature, symbolizing sluggish flow; and the flow temperature (FT), symbolizing liquid mobility.

R.K. Verma et al [14] studied the effect of basicity on the solidus and liquidus temperature of the blast furnace type slags. They have found that, generally liquidus and solidus temperatures are high for higher basicity slags. They have also studied the effect of Al_2O_3 on the solidus and liquidus temperature of blast furnace type slags. They have concluded that the solidus temperature is the lowest in the range of 30-33% Alumina content for both high and low

basicity slags. For higher basicity slags (B-1.66), addition of Alumina initially increases the liquidus temperature but later decreases. Liquidus temperature of lower basicity slags (B-0.82) decreases marginally up to 32-33% Alumina content and then increases. For the intermediate basicity slags (B-1.38), solidus and liquidus temperature increase with Alumina content.

H.A. Fine et al [15] studied the effect of minor constituents on the liquidus temperature of blast furnace slags determined at an oxygen potential of 10-15 atm. The slag samples contained 10% Alumina and had V ratios between 0.94 and 1.13. They have found that the effect of Titania on the liquidus temperature of the slag is strongly dependent on the oxygen potential. At low oxygen potentials, Titanium Oxide increases the liquidus temperature of the slag, while at high oxygen potentials; it decreases the liquidus temperature of the slag.

EXPERIMENTAL WORK

3. EXPERIMENTAL WORKS

3.1. Experimental Apparatus

High Temperature Microscope

The Heating Microscope method is adopted for recording the characteristic temperatures. A picture of the Leitz heating microscope is shown in Fig. 5. Schematic diagram of the instrument is presented in Fig. 6. The sample, in the form of a 3 mm cube, is heated in an electric furnace in the microscope assembly. The shape change of the sample as a result of heating is photographed by a camera. A grid-division which is simultaneously photographed with the sample and the temperature to which the sample is being heated facilitate identification of the four characteristic temperatures.

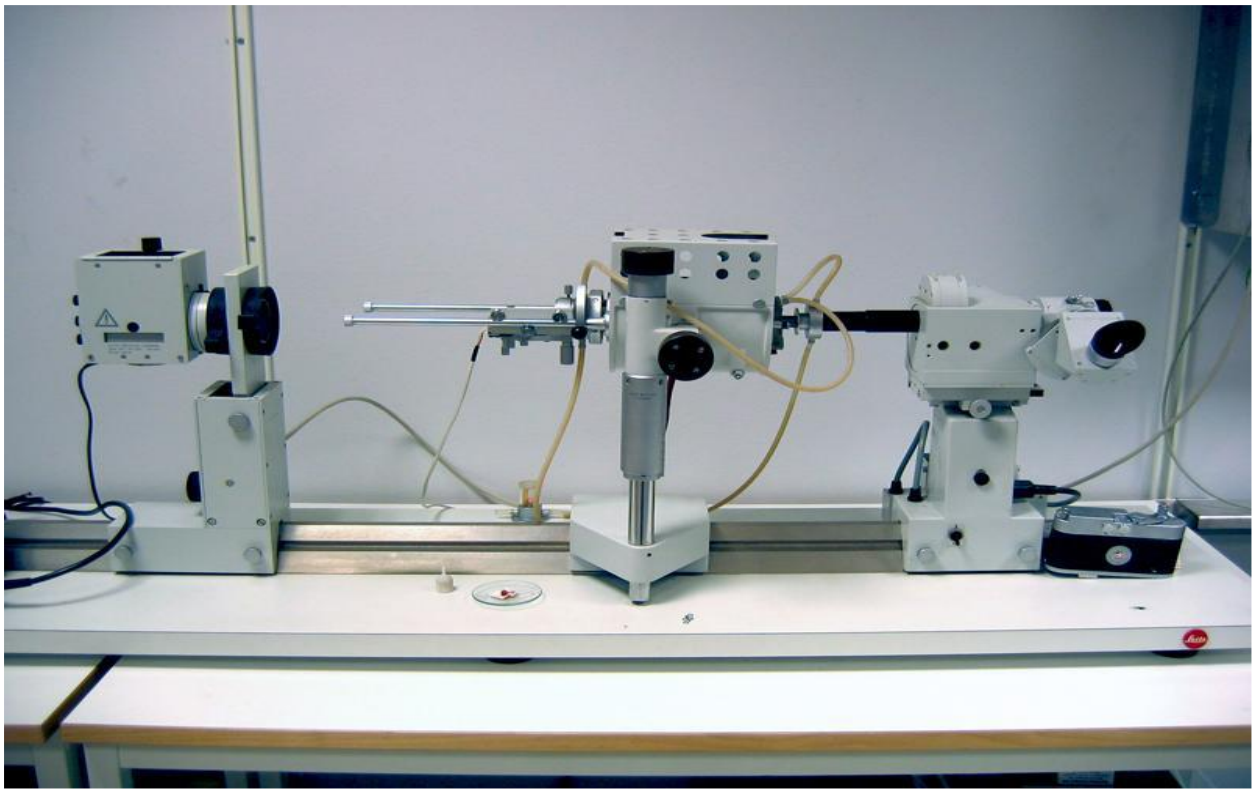


Figure 5. *Pictorial view of Leitz heating microscope*

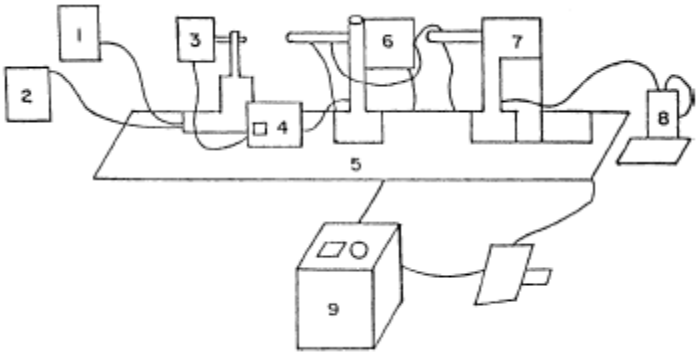


Figure 6.*Schematic diagram of the heating microscope*

1. Cooling water tank
2. Cooling water recirculating tank
3. Light source
4. Regulating transformer for light source
5. Optical bench
6. High temperature electrical furnace with specimen carriage
7. Observation and photo microscope
8. Digital thermometer
9. Regulating transformer for high temperature electrical furnace

Planetary Ball Mill

These mills are also referred as centrifugal mills and are used to grind samples into colloidal Fineness by generating high grinding energy. Fig. 7**.** represents a four stationed planetary mill presented by Gilson Company. The samples are placed in one of the vile and numerous balls are added as shown. The vile is covered by the cover plate and then it is mounted in the machine. Once the viles are mounted and secured, the machine is functional. The bowls are independent of the rotatable platform and the direction of rotation of the bowls is opposite to the direction of the rotatable platform. The motion resembles the teacup and saucer as seen in some of the amusement parks.

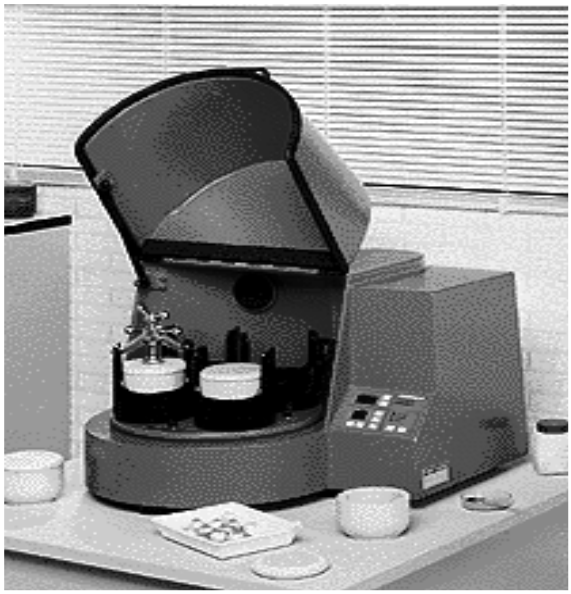


Figure 7. A four station Planetary Ball Mill

Due to alternate addition and subtraction of the centrifugal forces, the grinding balls rolls halfway in the vile and then thrown across the viles and then impacting the opposite walls at very high speeds. 20g acceleration is reached due to the planetary action and the time for the grinding reduces about 2/3 times than a simple centrifugal mill.

Sintering Furnace

The pellets obtained are sintered at around 1680 degrees Celsius in the sintering furnace to bind the slag material by the process of diffusion. This temperature is selected as it is the temperature that the slag undergoes when comes out of the blast furnace, so firing is done at this temperature. Proper firing can be easily done when homogenous mixing is done. There are two crucible holders where two platinum crucibles are places each containing different slags. Thus at a time 2 slags can be prepared. After attaining the required temperature gradually, the slag is then quenched in water to room temperature with the crucible in different containers.

Figure 8. *Sintering Furnace*

3.2. Experimental Process

The experimental work is planned in different phases, the aim being to determine the characteristics temperatures of the primary B.F. slag for proposing a composition that would indicate narrowed down. The phases of experimentation include the following:

- 12 slags were formed with C/S ratio 1.8, 2.0, 2.2 and 2.4 (3 slags for each C/S ratio) and a constant MgO of 10% was maintained throughout.
- Pelletization was carried out.
- Reduction was carried out in sintering furnace at different temperatures- 1200,1300,1400 C for samples with different C/S ratio, i.e., the three samples for each C/S ratio were reduced at 1200, 1300, 1400 C separately.
- Chemical composition analysis was carried out after reduction of the sample.
- The reduced sample was ground and was prepared for flow characteristic testing, i.e., heating microscope test.
- The characteristics temperatures, i.e., ST, HT, FT were noted down, and graphs were plot based on the observed values.
- Composition of slag after reduction of different C/S ratio

Composition (wt.%)	C/S=1.8, MgO=10%			C/S=2.0, MgO=10%		
	1200°C	1300°C	1400°C	1200°C	1300°C	1400°C
CaO	43.50	44.00	44.44	44.65	46.67	47.17
SiO_2	23.00	23.42	23.97	21.50	22.14	22.54
Al_2O_3	17.70	18.22	18.22	16.70	17.42	17.42
Fe_2O_3	03.00	01.00	00.00	05.00	01.00	00.00
TiO_2	02.20	02.70	02.70	02.20	02.61	02.61
MgO	10.50	10.60	10.60	09.33	10.23	10.23
CaO	42.65	46.17	48.08	43.30	47.47	49.24
SiO_2	19.20	20.26	21.16	17.80	29.61	20.35
Al_2O_3	16.55	17.95	18.45	16.00	17.61	18.27
Fe_2O_3	13.00	03.50	00.00	12.50	03.60	00.00
TiO_2	01.90	02.61	02.70	02.35	02.59	02.69
MgO	08.33	09.50	09.60	08.26	09.20	09.44

Table 1: Compositional Analysis after reduction

Preparation of samples for flow characteristic testing:

Sampling is usually done and especially for the case of **coning and quartering** for the purpose of checking the uniformity and the homogeneity of the sample prepared. For the method of coning and quartering the sample is first powdered and then laid out on a clean surface in the form of a conical heap. The cone is then quarters into four parts, following which only two opposite quarters are considered (like first and third) while the other quarters (second and fourth) are discarded. the samples are taken from each of the two opposite quarters and those small quantity of sample are formed into small cubes .The process is repeated as many times as necessary to obtain the quantity desired for some final use.

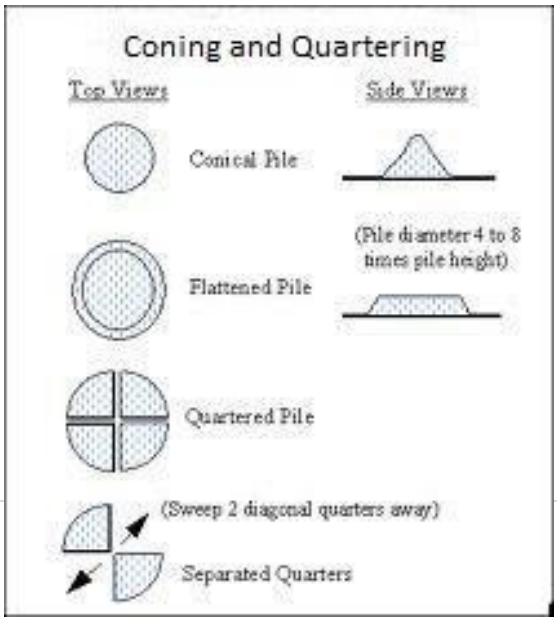


Figure 9. Coning and quartering views

The different steps for determining the flow characteristics are as follows.

- The sample, in the form of a 3 mm cube, is heated in an electric furnace in the microscope assembly.
- The shape change of the sample as a result of heating is photographed by a camera.
- A grid-division which is simultaneously photographed with the sample and the temperature to which the sample is being heated facilitate identification of the four characteristic temperatures.
- The temperature, at which the sample just starts to deform a bit, is reported as IDT.
- The temperature, at which the sample has already shrunk by exactly one
- The temperature, at which the sample takes the shape of a hemisphere with its height to diameter ratio 1:2, is reported as HT.
- The temperature, at which the height of the sample reduces to one-third of the height measured at HT, is reported as FT.

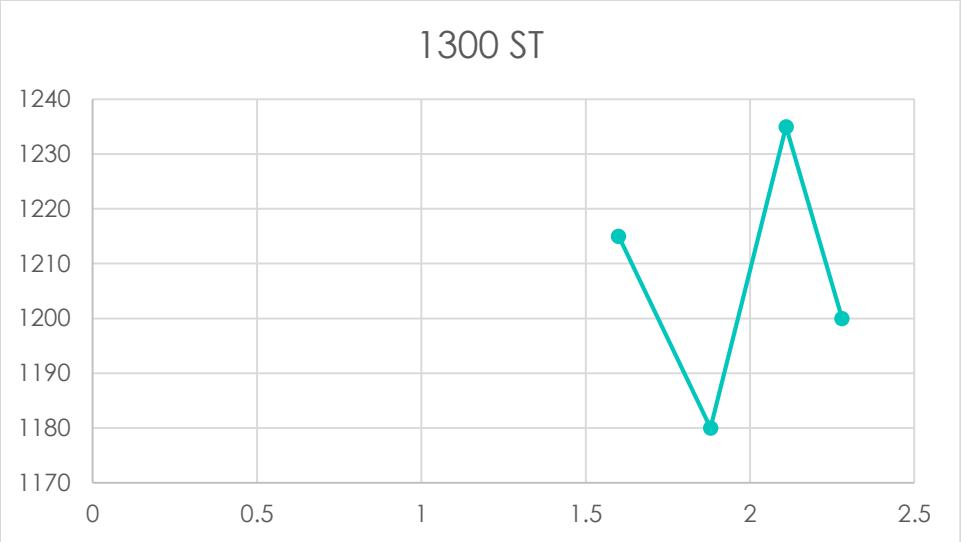
RESULT AND DISCUSSIONS

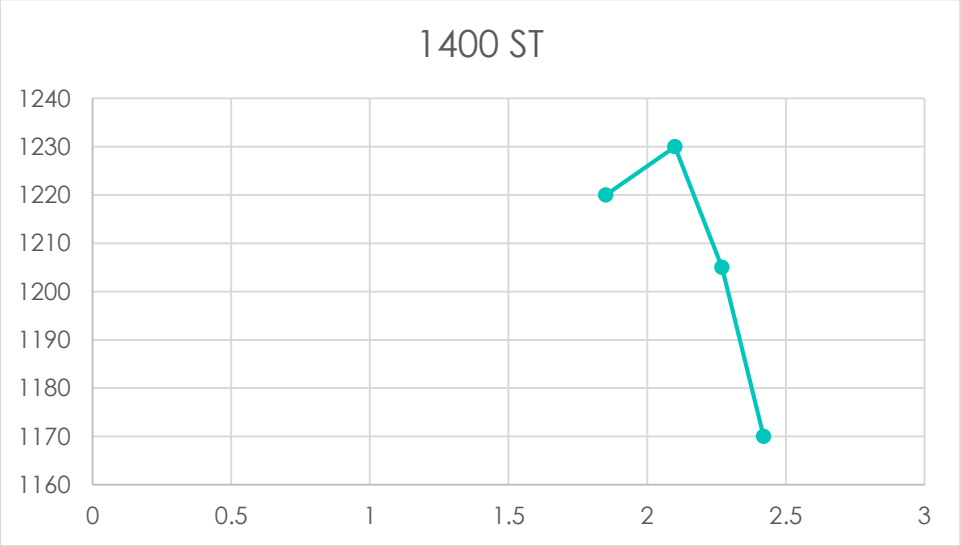
Results of Heating Microscope

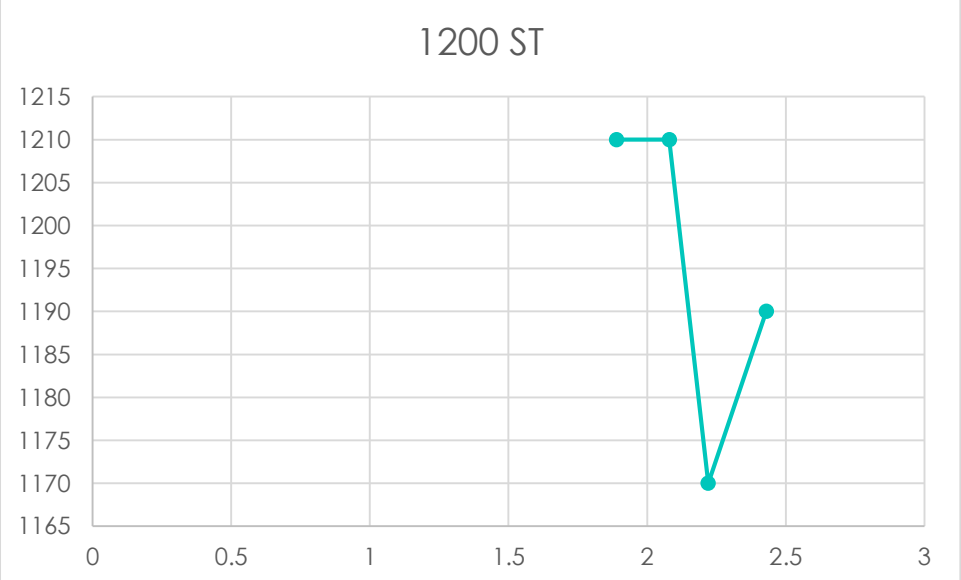
C/S ratio	Temp (°C)	ST(°C)	HT(°C)	FT(°C)
1.8	1200	1210	1320	1396
	1300	1180	1343	1428
	1400	1220	1347	1433
2.0	1200	1210	1335	1392
	1300	1235	1362	1405
	1400	1230	1374	1408
2.2	1200	1170	1382	1435
	1300	1200	1360	1442
	1400	1205	1380	1457
2.4	1200	1190	1362	1432
	1300	1215	1380	1425
	1400	1170	1393	1415

Table2. Results of heating microscope

PLOT BETWEEN ST OF DIFFERENT SAMPLES AND C/S RATIO





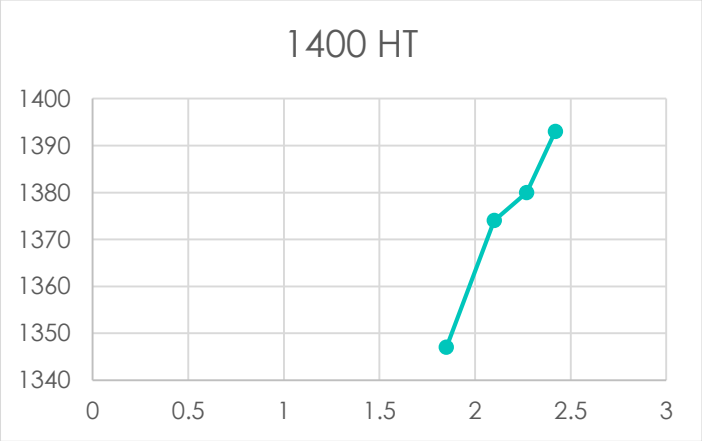


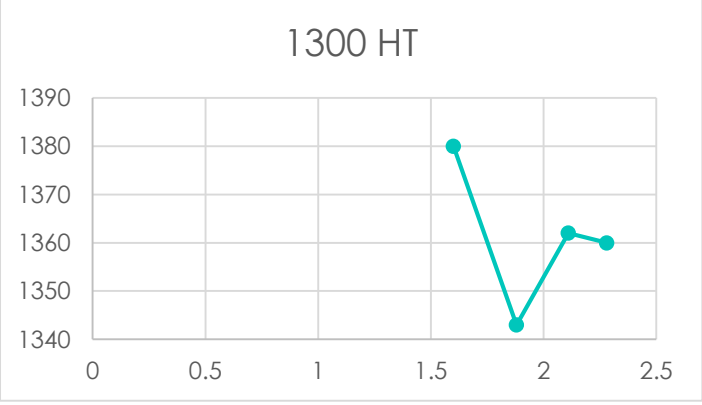
X-AXIS : C/S Ratio
Y-AXIS : Temperature in C

OBSERVATIONS FROM ST VS C/S RATIO PLOT

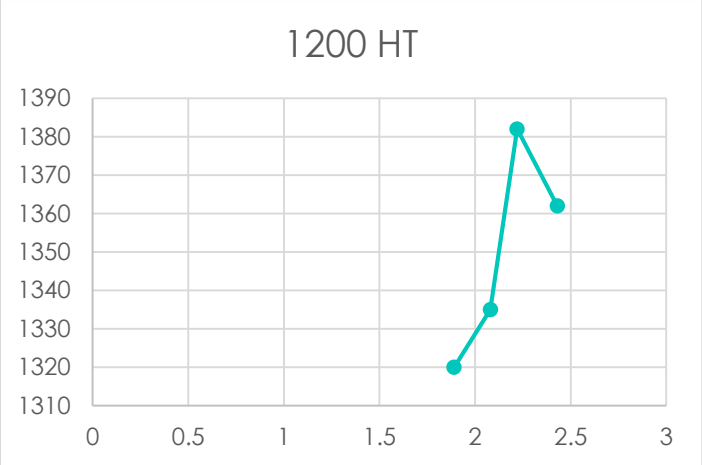
- The plot was not regular for all three samples, i.e., the samples reduced at 1200 C, 1300 C and 1400 C.
- However, it was observed that at C/S ratio 2, the slag generated from the pellet has the highest ST, i.e. , the slag generated by this pellet is formed lower down the blast furnace compared to others.
- Thus, our first aim, i.e. , to find the slag basicity having the highest Softening Temperature was achieved.

PLOT BETWEEN HT OF DIFFERENT SAMPLES AND C/S RATIO





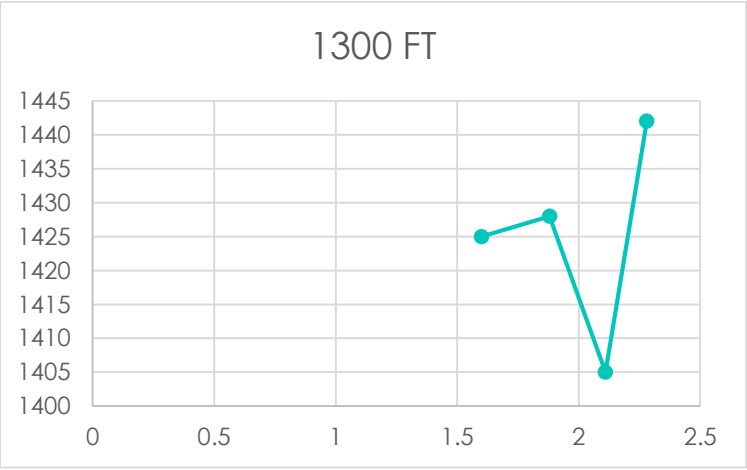
X-AXIS : C/S Ratio
Y-AXIS : Temperature in C



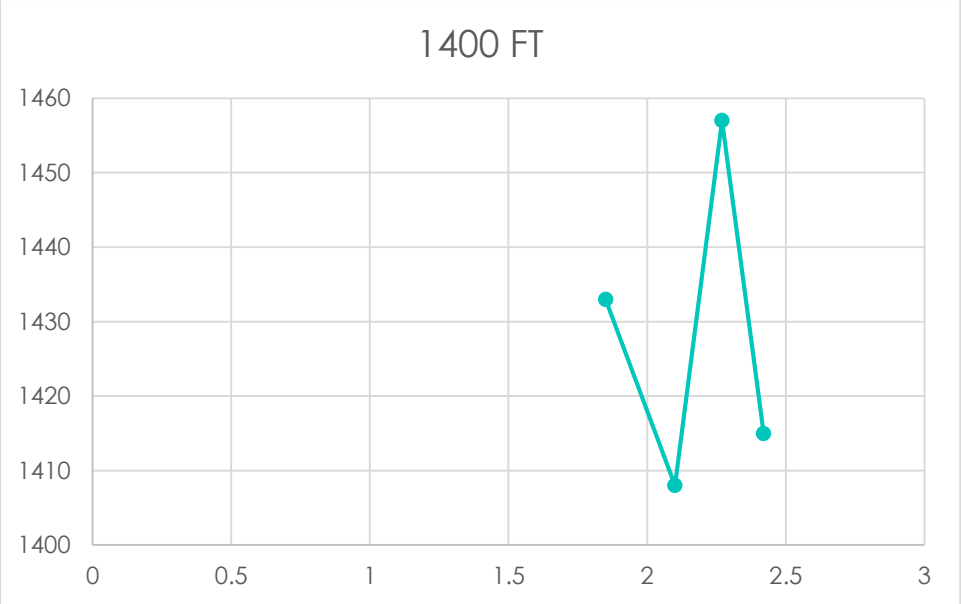
OBSERVATIONS FROM HT VS C/S RATIO PLOT

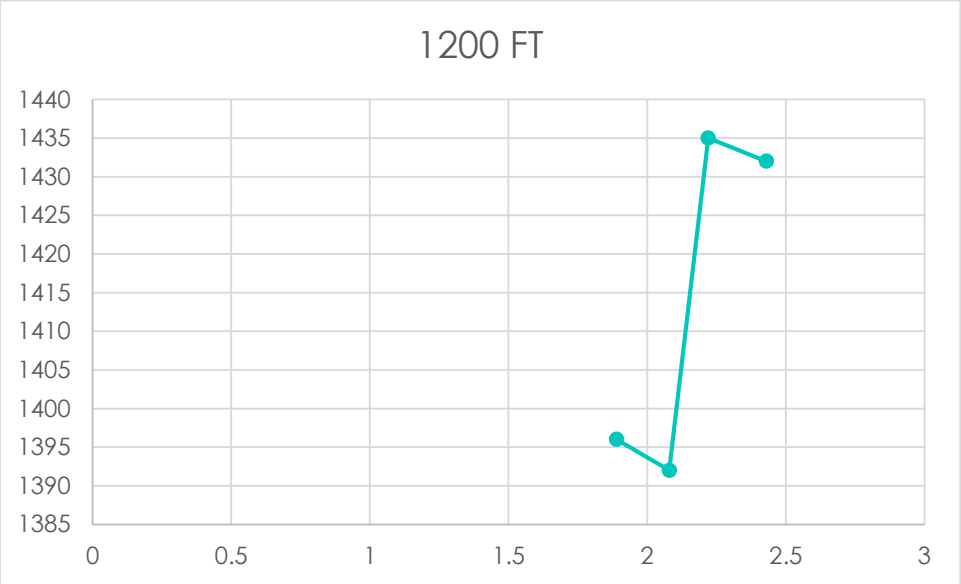
- Again. No regular trend was found.
- Neither the values corresponding to the previously observed C/S ratio of 2 were highest.
- However, we for an effective lowering of cohesive zone we need to consider only the Softening Temperature and Flow Temperature and Hemispherical Temperature has no say in it, thus this observation can be ignored.

PLOT BETWEEN FT OF DIFFERENT SAMPLES AND C/S RATIO



X-AXIS : C/S Ratio
Y-AXIS : Temperature in C

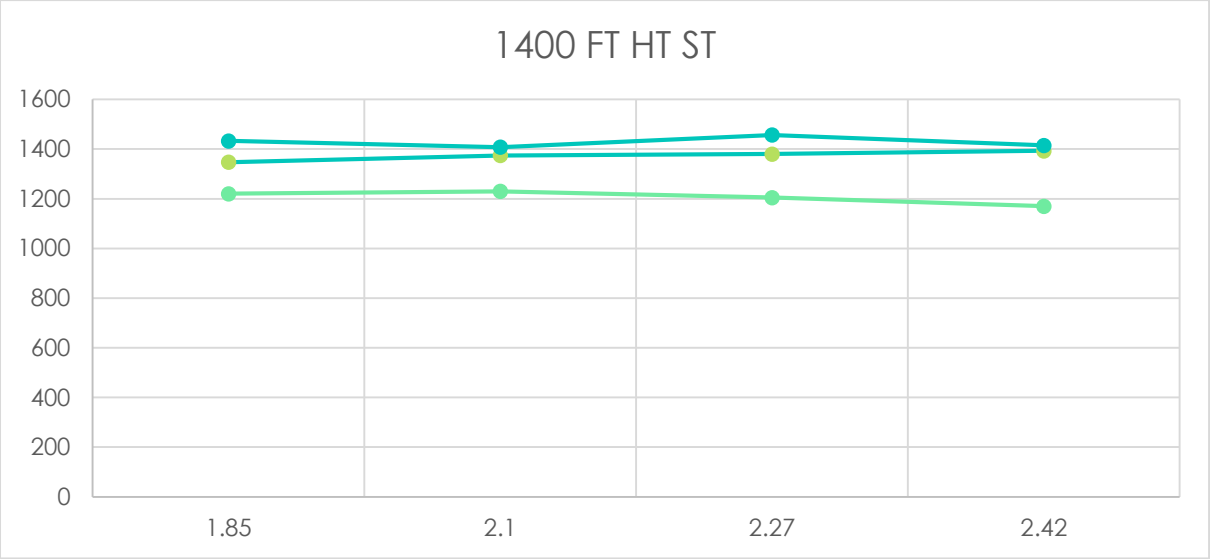


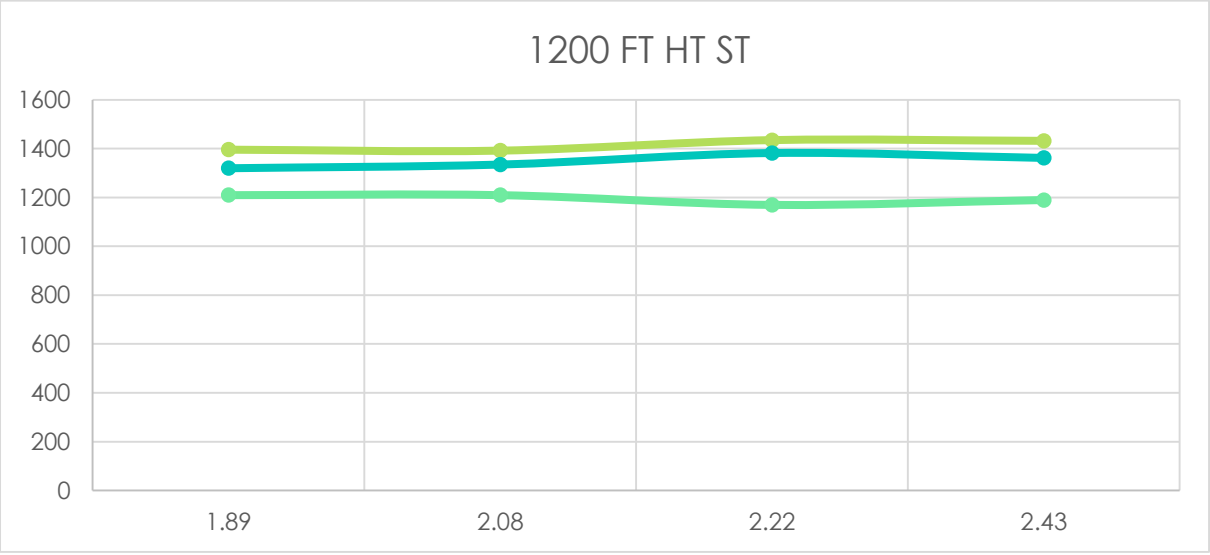


OBSERVATIONS FROM FT VS C/S RATIO PLOT

- The values seemed to decrease in and around the C/S ratio of 2.
- Infact, the least FT values were obtained close to or at C/S ratio 2.
- Thus, the slag generated from these pellets, C/S ratio 2, completely liquidifies at the lowest temperature, i.e. , it liquidifies at soon as posible.
- Hence, our second aim of obtaining a slag which has the lowest FT is achieved.

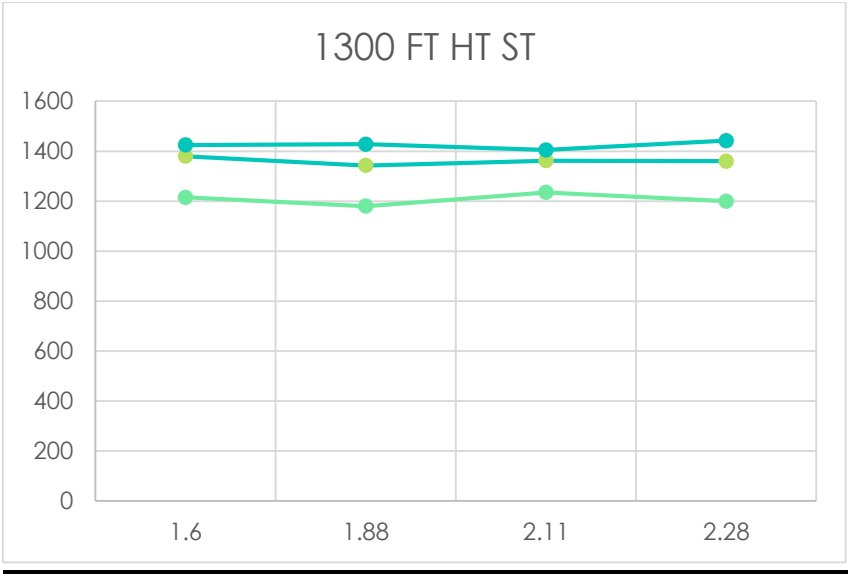
PLOT BETWEEN FT,HT AND ST OF DIFFERENT SAMPLES AND C/S RATIO :





X-AXIS : C/S Ratio
Y-AXIS : Temperature in C

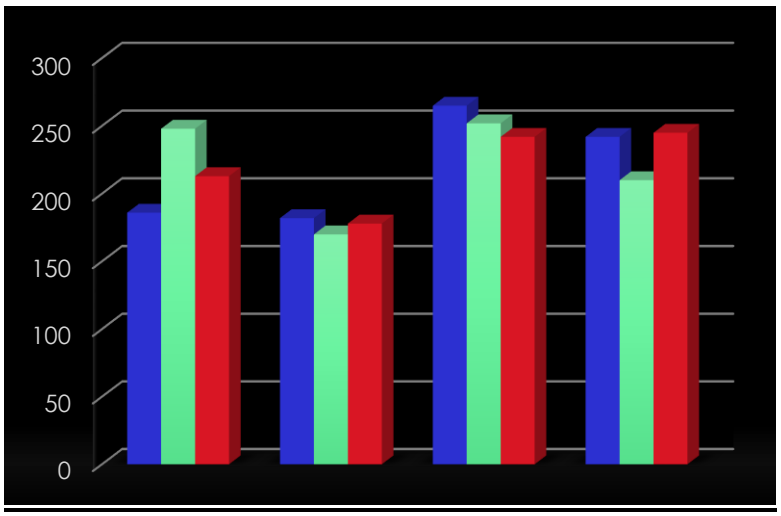
Series 1 : FT
Series 2 : HT
Series 3 : ST



OBSERVATIONS FROM FT,HT AND ST PLOT OF DIFFERENT SAMPLES VS C/S RATIO:

- Physically, the width of the plot represents the extension of cohesive zone.
- As evident from the plot, the plot seems to narrow down in the vicinity of C/S ratio 2.
- It suggests that the from the samples tested, the sample which generates a slag with C/S ratio 2 will earn the narrowest cohesive zone.

C/S RATIO VS (FT-ST) FOR 1200 C 1300 C 1400 C



X-AXIS : C/S Ratio
Y-AXIS : Temperature in C

Series 1 : FT – ST FOR 1200C
Series 2 : FT – ST FOR 1300 C
Series 3 : FT – ST FOR 1400 C

OBSERVATIONS FROM C/S RATIO VS (FT-ST) FOR 1200 C 1300 C 1400 C :

- The above plot directly shows the temperature range between which the cohesive zone lies at different C/S ratio and reduction degree.
- It is clearly evident from the plot that, at C/S ratio of 2, the cohesive zone has the least temperature range, hence the narrowest.
- Moreover, from the previous observations it was found out that, at C/S ratio of 2, the slag had a HIGH ST AND LOW FT.
- Thus, the results hold in favor of the experiment and the narrowest cohesive zone was observed when the slag has a C/S ratio of 2

along with the fact that, it has HIGH ST AND LOW FT, suggests that it appears at the lowest possible location of the blast furnace.

Overall Discussion(SUMMARY)

- As evident from the graphs, sample with C/S ratio 2 is the most suitable one. The slag generated from this pellet exhibits the maximum S.T. Such a slag will soften lower down the furnace resulting in the lowering of the cohesive zone of the furnace. This slag further has the lowest flow temperature, this indicates that the cohesive zone will be narrowed for their pellet with C/S ratio 2.
- Lowering down the cohesive zone will result in extension of the granular zone in the blast furnace this will provide for greater extents of indirect reduction. This will ensure a better utilization of Blast Furnace gas in the furnace and thus results in lesser coke consumption.
- The distance travelled by the upcoming gas laden with SiO before it encounters the descending metal droplets reduces considerably with the lowering down of the cohesive zone. This results in decrease in the silicon pickup by the hot metal, thus improving its quality.
- On the basis of the above, it can be concluded with the emphasis that the pellet with '2.0' C/S ratio is the ideal choice concerning, the coke consumption and quality of the hot metal produced in the Blast Furnace.

CONCLUSION

4. CONCLUSION

It was concluded that the slag with the C/S ratio of 2 with the following composition:

	C/S=2.0, MgO=10%		
	1200°C	1300°C	1400°C
CaO	44.65	46.67	47.17
SiO_2	21.50	22.14	22.54
Al_2O_3	16.70	17.42	17.42
Fe_2O_3	05.00	01.00	00.00
TiO_2	02.20	02.61	02.61
MgO	09.33	10.23	10.23

has the highest ST, i.e. , it starts to liquidify lower down the blast furnace, and also possesses the lowest FT , i.e. , when it completely liquidifies, thus suggesting that the cohesive zone formed by this composition lies lowest in the blast furnace and is the narrowest one. Hence, has the largest granular zone and the Si pickup is also the least and thus will serve us the purpose of producing hot metal more efficiently with relatively low coke, better bed permeability, better reducing atmosphere in the BF and a hot metal product with low Si content.

5. REFERENCE

1. Nogueira Paulo F. and Fruehan Richard J., Metallurgical and Materials Transactions B, 35 B, 2004, p 829
2. Kaushik P. and Fruehan Richard J., Ironmaking & Steelmaking, 33, No. 6, 2006, pp. 507-519
3. Clixby G., Softening & Melting of super fluxed sinters and acid pellets, BSC, Ironmaking Session, Tesside Laboratories, International Report,1979
4. Potebnyaj et al, Steel USSR 3, 1973.
5. German Industrial Standard 51730.
6. Taskanen P.A., Huttunen S.M., Mannila P.H. and Harkki J.J., *Ironmaking & Steelmaking*, 29, 2002, pp. 281-286.
7. Biswas A.K., Principles of Blast Furnace Ironmaking, Calcutta: SBA Publications, 1984
8. Ghosh Ahindra and Chatterjee Amit, Ironmaking and Steelmaking – Theory and Practice, New Delhi: PHI Learning Private Limited, 2010
9. Kaushik P. and Fruehan R.J, Iron Making and Steel Making, 2004
10. Kaushik P. and Fruhen J., Mixed Burden Softening and Melting, Iron Making and Steel Making, Volume 33(Issue 6), 2006, pp. 507-519
11. Osborn E. F. et al., Process Blast Furnace, Coke Oven and Raw Materials Conference, 1953
12. 10. Snow R. B., Proc., AIME, 1962
13. Ohno A. and Ross H. U., Can. Metall. Q., 2, 1963, p 243.
14. Verma R.K., Ray H.S., Ghosh A., Singh R.N and Dharnipalan S., Transactions of Indian Institute of Metals, Vol. 32. August 1979
15. Fine H.A. and Arac S., Ironmaking and Steelmaking, 1980
16. http://www.cwc.org/glass/gl_htm/gl979rpt.htm/12-02-2012
17. IUPAC Compendium of Chemical Terminology, 2nd Edition, 1997